

1. deBroglie particle-wave duality

deBroglie particle-wave duality

- Started with "What is the λ for e^-" ?
- Analogy with photon to obtain: $\lambda = h/p$
- deBroglie used this to explain Bohr's quantized e^- orbits in H atom
- Opens up possibility that all massive objects have wave-like properties
- deBroglie wavelength of massive particle

$$\lambda = h/p \qquad \text{(for any } m_0 \neq 0\text{)}$$

Ex. $m_{baseball}$=0.17 Kg, v=100 Km/hr $\rightarrow$ $\lambda = 1.4\text{x}10^{-34}$m (~size of interference pattern $\Rightarrow$ not observable)

m_{proton}=1.7x10^{-27}Kg, e.g. v=c/100 $\rightarrow$ $\lambda = 1.3\text{x}10^{-13}$m (~ nuclear size so effects proton's properties within nuclei)

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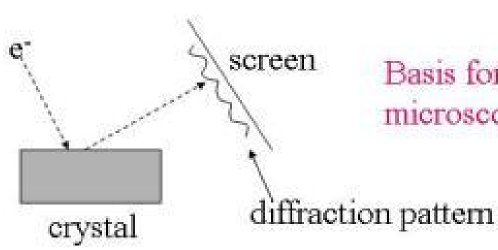
2. Electron wave effects

Electron wave effects

- e^- 's should show diffraction for material spacing same order as deBroglie wavelength
- Crystal diffraction - Davisson & Germer (1927) (analog of X-ray diffraction) - e^- beam at fixed *p* or *E*



Basis for electron microscope

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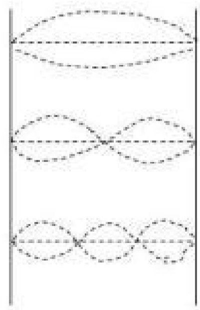
3. Standing e- waves

Standing e^- waves

deBroglie→ wave pattern in a circular orbit. What about wave pattern in linear case? Electron in narrow tube. Standing waves like vibrating string.



n=1

n=2

n=3

1 dim box - length L (string modes)

$\lambda_1 = 2L$, $p_1 = h/2L$,

$E_1 = 1/2\ mv^2 = p_1^2/2m = h^2/8mL^2$

$\lambda_2 = L$, $p_2 = h/L$, $E_2 = h^2/2mL^2$

$\lambda_3 = 2L/3$, $p_3 = 3h/2L$, $E_3 = 9h^2/8mL^2$

: : :

$\lambda_n = 2L/n$, $E_n = n^2 h^2/8mL^2$

Harmonics of strings ≈ quantum states
Music of the atoms!

Modes or stationary states of definite energy for system
Where is the electron?

There is no zero energy state!

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4. Electron Wave Function

Electron Wave Function

- From *kinematics* to *dynamics*
- A wave needs a **wave equation** ➡
- Schrödinger Equation (1928) wave mechanics
  - (cf. Heisenberg, Born, Jordan matrix mechanics)
  - Very exciting time! Next read play Copenhagen.
- $\Psi(\underline{x},t)$ wave function or amplitude- solution
- complex valued function (real & imaginary parts)
- H atom: wave "modes" $\Psi_n(\underline{x},t)$ -> solutions with same E_n as Bohr (also other quantum numbers)
- More generalizable to other atoms Success!

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5. Wave function particulars

Wave function particulars

- complex valued function in general (important for interference)
- H atom: wave "modes" $\Psi_n(\underline{x},t) \rightarrow$ stationary solutions for definite $f_n \rightarrow$ same E_n as Bohr (also other quantum numbers: *l, m* for ang.mom.)
- More generalizable to other atoms Success!
- Now have wave modes of e^- around nucleus
- Following illustrations of electron wave modes for H atom will be called Probabilities or Probability clouds or Probability distributions. Will be interpreted later.
- Emission or absorption of γ when e^- "jumps" from $E_{initial}$ to $E_{final} \Leftrightarrow hf$ for γ. f is like the "beat" frequency between $E_{initial}/h$ and E_{final}/h (see Hoffmann's discussion of Schrödinger - more music of the atoms)

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6. Radial probabilities (r2|?(r)|2)

Radial probabilities ($r^2|\Psi(r)|^2$)

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Note units of r are a_0 = smallest Bohr radius = 0.5×10^{-10}m

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7. More radial probabilities

More radial probabilities

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8. Hydrogen Probability Clouds I

Hydrogen Probability Clouds I

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9. Hydrogen Probability Clouds II

Hydrogen Probability Clouds II

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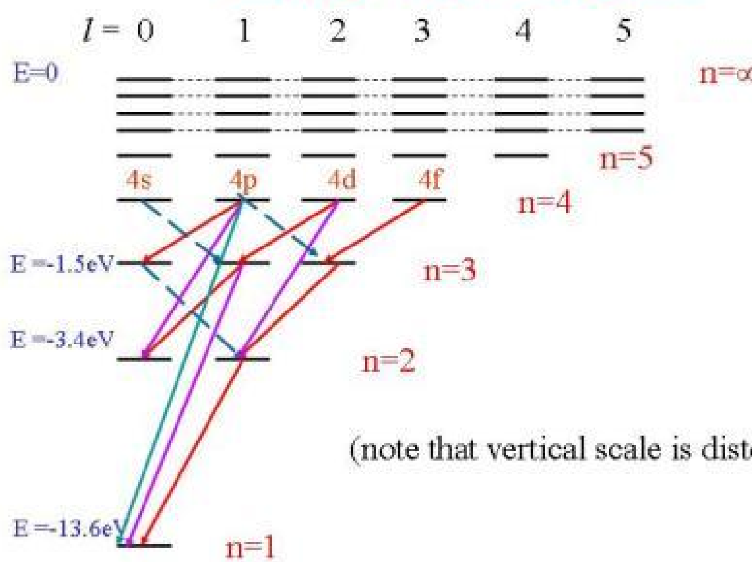
10. Energy level diagram

Energy level diagram



(note that vertical scale is distorted)

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11. Interpreting electron’s ?(x,t)

Interpreting electron's $\Psi(\underline{x},t)$

- Interpretation? cf.strings, sound, water waves, EM waves
- All waves have traveling modes and stationary modes, depending on shape of system, forces on system, initial conditions, etc.
- **What is waving**? Meaning of $\Psi(\underline{x},t)$ for e^- or any wave-mechanical particle described by Schrödinger equation.
- Time for development of an interpretation. Exciting times in **Copenhagen** with Bohr, Heisenberg, Born, Jordan, et al.
- Consider EM waves also and wave-particle duality - varying E force field vs. photons. How can this be interpreted?

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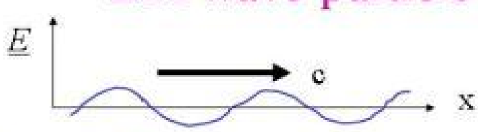
12. EM wave-particle duality

EM wave-particle duality



- Maxwell: Energy/vol & Intensity~ $\underline{E}^2$ (or $\underline{E}^2 + \underline{B}^2$) ($\underline{E}$ is electric force field. Use E-force symbol.)
- But quanta have E = hf. How to reconcile?
  - Recall that 40 W light bulb with peak λ near 500 nm, each γ has E~4×10^{-19}J. Hence no. γ's ~ 40J/s÷4×10^{-19}J ~10^{20} γ's/sec . Can not distinguish γ's.
- *Caveats:* single slit can narrow, observer uses photons, collapsing wave function vs. interaction with environment
- Also see recent NY Times article on "Far Out Quantum Physics" in Course Documents

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